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ABSTRACT

Noting that formative research on educational computer software has traditionally focused on comprehensibility, appeal, and usefulness, this report argues that these three elements tell us very little about the actual role that the formative researcher plays in the instructional design process. This paper outlines the complexity of the tasks and skills required in formative research by presenting a case study of the design of an educational computer program, "Maya Math," one of the classroom modules developed as part of the "Second Voyage of the Mimi" project at Bank Street College of Education. (GL)

BANK STREET COLLEGE OF EDUCATION

CENTER FOR CHILDREN AND TECHNOLOGY

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THE ROLE OF FORMATIVE RESEARCH IN THE DESIGN OF EDUCATIONAL COMPUTER SOFTWARE

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What is Formative Research?

In the design of educational computer software, formative research is responsible for assessing three fundamental issues: (1) comprehensibility, (2) appeal, and (3) usefulness. Comprehensibility research investigates both the clarity of the educational ideas contained within the software and the clarity of the interface that enables the user to interact with the program. Appeal research addresses the popularity of the basic activity among the target audience, and usefulness research evaluates the educational effectiveness of the product. Although these three elements constitute the objectives of formative research, they tell us very little about the actual *role* that the formative researcher plays in the design process.

The reality of the formative design process is far less neat. Since formative studies done in nonacademic settings are often conducted on a very small scale, with little time to reflect, revise, or reconsider, the researcher must invariably reach conclusions on the basis of incomplete evidence. Thus, a solid background in developmental and educational psychology is necessary to place into a reliable context the impressions gathered from research.

In many ways the formative researcher functions both as a troubleshooter for the designers and as an advocate for the target audience. She/he must be able to translate the concerns of the designers into quickly answerable research questions, and then translate the responses of the audience into recommendations for the designers. At times, she/he must also translate the implementations of the designers into theoretically defensible pedagogical objectives for the educational establishment, and the suggestions of academic advisors into concrete guidelines for the production staff. Throughout all this, the formative researcher must keep a clear view of how to make the best possible products for children.

In this paper, I will illustrate the complexity of the tasks and skills required in formative research by presenting a case study of the design of an educational computer program, "Maya Math," one of the classroom modules developed as part of *The Second Voyage of the Mimi* project at Bank Street College of Education. The *Mimi* classroom modules differ from the design premise of other educational software programs insofar as they comprise both software and print materials. As a result, the software is not expected to carry the entire pedagogical burden. I will use the context of Maya Math to illustrate how the specific issues outlined above came into play in the design of this learning module.

The Educational Context

Before addressing the formative work we carried out, I will describe the context in which this software program was created and discuss some of the educational objectives that formed the backdrop of the design process. *The Second Voyage of the Mimi* is a federally funded multimedia project in math and science education for upper elementary school students. The centerpiece of the *Mimi* is a 24-part television show that focuses on Maya archeology in the Yucatan Peninsula of Mexico. The story features a young boy and his grandfather, who become involved in an adventure that leads them into an extensive exploration of Maya life—both past and present.

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Each episode of the drama is followed by a documentary expedition, in which one of the young actors visits a scientist and explores in depth a topic touched upon in the dramatic series. The computer classroom modules are also used to further elaborate upon themes contained in the videos. In addition to the Maya Math program, the second season classroom modules include a solar astronomy simulation.

The Maya Math program is designed to present a particular aspect of mathematics as an archaeological discovery. In the module, students are asked to adopt the role of archaeologists attempting to decipher the meaning of Maya number glyphs. (The Maya number system is a base twenty system that uses three number symbols: a shell stands for zero, a dot stands for one, and a bar stands for five. See Figure 1.)

The print materials encourage the teachers and students to use an open-ended hypothesis building and testing approach as they try to make sense of the Maya system of writing numbers. In the course of their investigations, students encounter basic mathematical concepts, such as numeration and the invention of zero. Most important, Maya Math serves as a reintroduction to the concept of place value.

The computer software features a "Maya Calculator," which functions as a tool used to facilitate the process of understanding the Maya base twenty system and other bases as well (see Figure 2).

The software also includes a Maya number game, "Glyph Trek," which is modeled on the adventure story of the television show, and a "Maya Calendar" used to explore how the Maya kept track of time by

Figure 1. Counting to 21 in the Maya number system

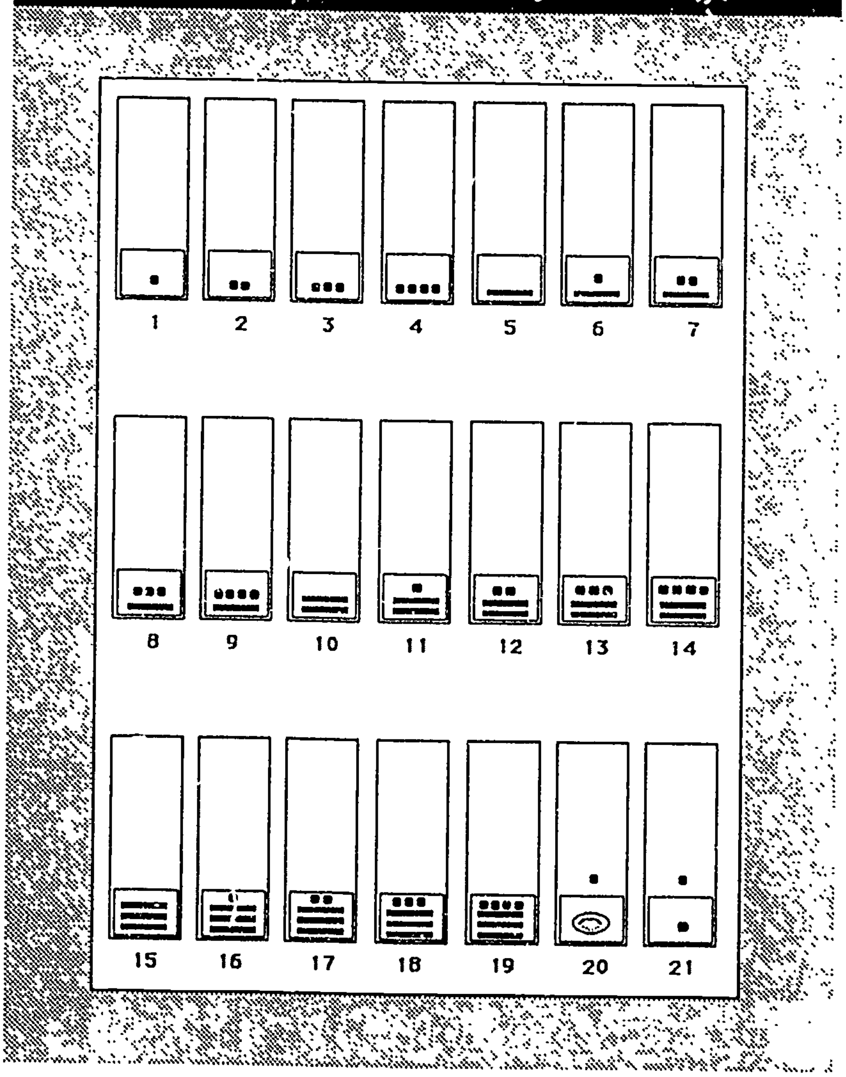
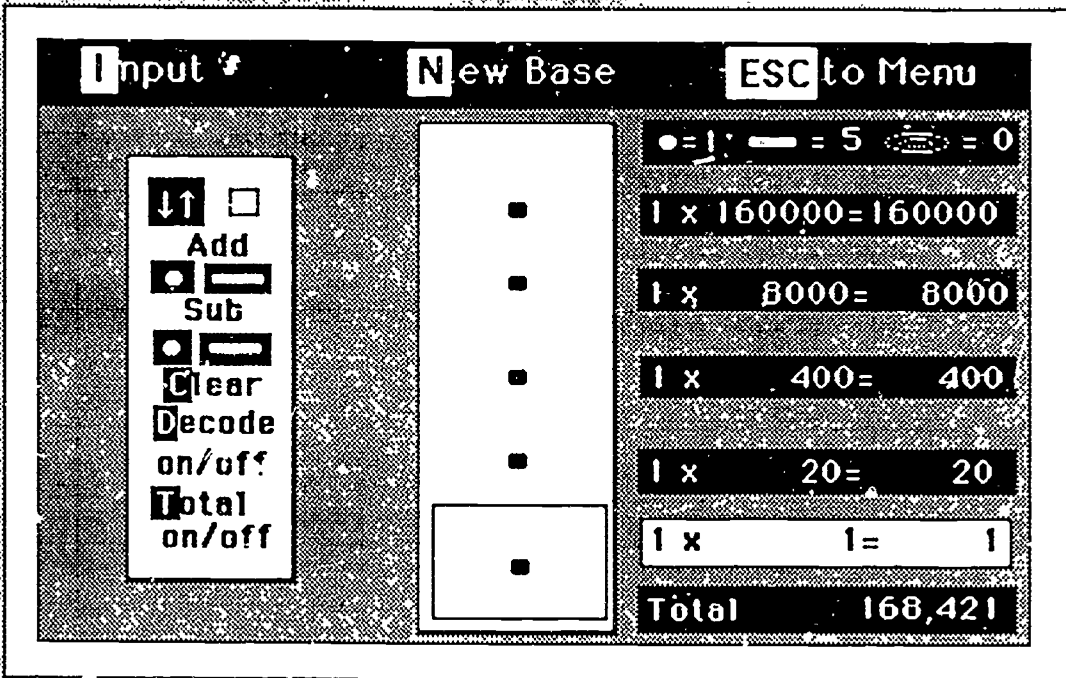


Figure 2. Maya Calculator



counting days.

The formative research carried out in conjunction with the design process was conducted over a four-month period and involved both the software and print materials. Five fourth- through sixth-grade classrooms were involved in the evaluation. The students came from a variety of socioeconomic groups, and the teaching styles varied from more traditional teacher-led approaches to student-centered classrooms.

The research was conducted in three phases: The first involved testing the concepts central to the workings of Maya Math. The second phase involved evaluating a prototype version of the Maya Calculator, and the third involved evaluating the program as a whole in conjunction with a draft of the print materials. Rather than concentrating on each phase of research as a distinct entity, this paper will discuss the three factors that must be assessed in the development of any educational software program: comprehensibility, appeal, and usefulness.

The Assessment of Comprehensibility

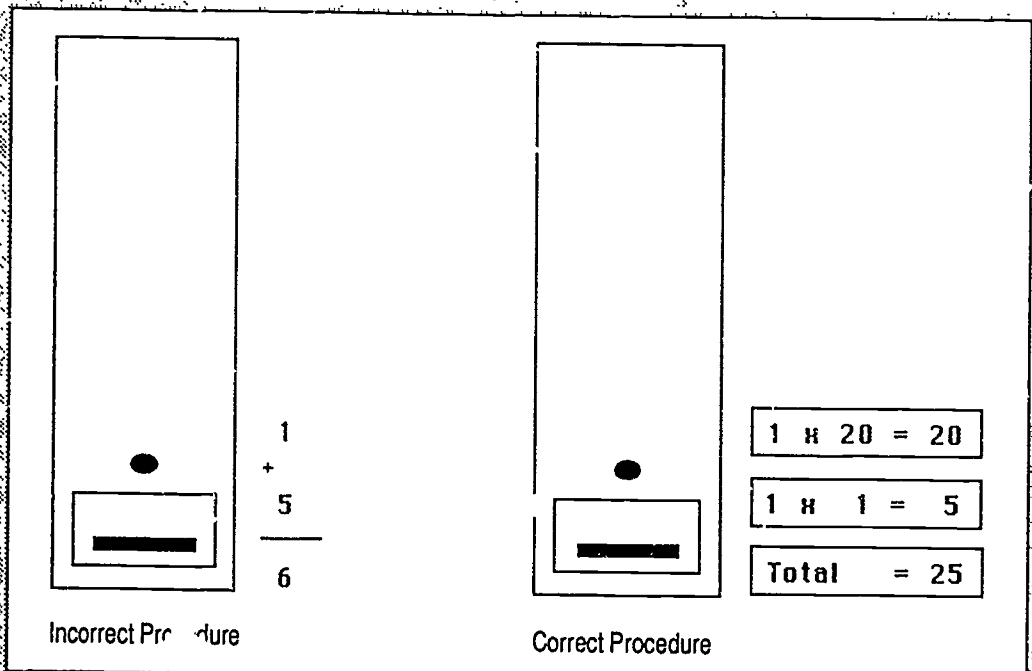
In many respects, assessing the comprehensibility of educational software is the most difficult and also the most important task the formative researcher faces. On the surface, comprehensibility research appears to be a straightforward investigation of the clarity of the educational ideas contained within the software and the clarity of the user interface. The researcher, however, soon runs up against an inevitable fact—students of differing abilities must be able to use the software effectively. Part of what is involved in assessing comprehensibility is determining the range of variability in students' understanding of the software's central concepts and making recommendations to the design team about ways in which to accommodate various abilities. In addition, an assessment of comprehensibility is necessary to create a basis from which the issues of appeal and usefulness can be interpreted. Comprehensibility research, therefore, lays an important foundation from which other issues that are of concern to the design team can be investigated.

During the earliest phases of our research, we designed an off-line version of the Maya Calculator using a cardboard stela (an upright stone slab carved with inscriptions, on which the Maya typically carved historical information) and paper cutouts of dots, bars, and shells. Our purpose in doing this was two-fold: We wanted to get an indication of the kinds of conceptual problems students were likely to encounter as they worked with different number symbols in another place value system, and we wanted to assess the range of student understanding. We found that all the students we worked with were quite capable of using the Maya number symbols to build numbers less than twenty. However, it became clear that students were at various levels in their understanding of the concept of place value when they began to work with these number symbols in a base twenty system

The students fell into three easily identifiable groups. The first was composed of students who appeared to have a technical or rigid understanding of place value. Given an Arabic number, they were able to identify the one's, ten's, hundred's, and thousand's place, but they had no underlying conceptual basis for understanding how place value works. Although these students were able to convert Maya numbers less than nineteen, they were at a complete loss when asked to convert Maya numbers greater than twenty. The most common error they made was to ignore the operations of place and add all the Maya dots and bars together. For example, when given a number that had a bar in the one's place and a dot in the twenty's place, the students would decode this number as six instead of twenty-five (see Figure 3).

For students who lack a conceptual framework in which to locate Maya Math, the arithmetical operations involved in this program prove to be mysterious. Not only do students need to remember what the Maya symbols stand for and the value of the different places, but they also have to apply the correct algo-

Figure 3. Incorrect and correct procedures for decoding the Maya number 25



rithm to decode or encode a given number. Once the design team had information about the specific areas in which these students were having difficulty, they were able to make changes in the software that accommodated the particular needs of this group. We decided that these students needed a simple but motivating route into working with Maya numbers, which led eventually to the creation of Glyph Trek, a number decoding game that can be played at a very elementary level.

Additional research made it apparent that our prototype help screen did not aid these students in distinguishing among the various operations that are necessary when translating Maya numbers into their Arabic counterparts. We agreed that a traveling cursor should be used to selectively highlight each algorithm in order to differentiate one operation from the next. Finally, in the accompanying print materials, a number of basic, yet engaging activities were designed to help this group develop a better understanding of place value.

The second group of students had a much easier time with the concept of place value than did the first group. Although, like the first group, they lacked a solid conceptual understanding of place value, with practice they developed a firmer grasp of the concept. The design changes made to accommodate the first group also proved to be extremely helpful to these students. We decided to incorporate different levels into Glyph Trek so that these students could play a more challenging game while developing their understanding of the basic, yet essential operations involved in Maya math. Using the traveling cursor to highlight the help screen also proved to be useful in alleviating misunderstandings.

These students presented an additional challenge. Once they had mastered some of the fundamental concepts, we were faced with the "so what's next" problem. Many students assumed that they had learned all that there was to learn about Maya Math, when they were not in fact ready to take on some of the more challenging aspects of the software. Their inability to meet certain challenges successfully was a major source of discouragement.

We were faced with the problem of creating an intermediate activity that would hold students' interest while at the same time helping them to develop a solid understanding of place value concepts. We created an off-line version of the game "21," called "To the Limit," in which students, playing in pairs, roll either Maya or Arabic number dice and attempt to be the first to reach 21. In this game, the player may decide to subtract her/his roll from the opponent's total or add to her/his own total. This activity involves all of the essential elements of doing arithmetic using Maya numbers—grouping, trading, and place value. When students have mastered this simple version, they can choose a larger number as their goal. This game was a huge success, serving as a kind of transitional environment that enabled students to move on to more complicated aspects of the software.

The third group of students we encountered had a well-developed conceptual understanding of the concept of place value. They had little trouble, if any, in mastering the Maya number system. The problem that we faced was how to ensure that the software would be rich enough in challenges to hold their attention for sustained periods of time. These students often began playing Glyph Trek at the hardest level and quickly lost interest. Similarly, they often felt that they had nothing to learn from the calculator and were easily bored. The formative research made it very clear that the software and print materials would have to include a number of stimulating activities aimed directly at this group of students. As a result, the calculator contains a number of features that can be used as challenge activities; for example, the computer picks a base and the student guesses what it is, or the student hides the base and challenges a partner to guess it. In addition, the print materials contain mystery number puzzles as well as a number of intriguing thought problems that require the help of the calculator to solve. The print materials also encourage these more advanced students to play To the Limit in different number bases.

The Assessment of Appeal

Although not as difficult to assess as comprehensibility, the evaluation of a software program's appeal contains its own set of problems. Most important, it is necessary to ascertain whether a student genuinely dislikes a program or whether she/he dislikes the program because of a failure to understand some critical aspect of it. In the development of Maya Math we were always walking a fine line discriminating between these two phenomena.

The calculator, in particular, presented us with an interesting challenge. At the outset of the development process, the design team made a conscious decision to create a software tool rather than a software game. There were several reasons for this, ranging from the initial scope of the project, to the amount of time available, to the fact that the subject matter lent itself nicely to the lculator format. The most immediate reaction we received from students was one of displeasure. Some of this displeasure was genuine and some, as should be clear from the above discussion, had to do with the fact that certain students were unable to understand basic components of the software program.

With the first group of students, it was apparent that their displeasure had to do with their lack of understanding. It became clear that they needed an entertaining and motivating path into the calculator. The result, as explained above, was Glyph Trek.

The other two groups of students presented us with a different dilemma. Although they were initially interested in and curious about the calculator, their interest waned with time. The research we carried out made it apparent that the calculator was simply not entertaining enough. Our recommendation to the design team was to create an on-line version of the To the Limit game. Time and resources intervened, however, and the game never materialized as an on-line activity. As an alternative, the print materials contain a note to teachers suggesting that students create their own game boards and play off-line. The reality of any software development project is that there are always instances in which priorities other than research must prevail. More often than not, decisions come down to what is economically feasible.

The Assessment of Usefulness

Finally, determining the educational effectiveness of a software product is something that formative research can only evaluate in the most superficial way. To assess whether or not a program actually helps a child learn something of value is the prerogative of more formally planned academic research. However, the formative researcher can get a *general* reading on the educational effectiveness of the product and she/he can also assess whether the product is useful to teachers.

The formative research carried out on Maya Math undertook to do two things:

1. From the beginning of the development process, we invited teachers to comment on the educational objectives of the program, the design of the software, and the content and form of the print materials.

2. We also paid close attention to students' initial understanding of the software and whether their understanding seemed to improve as they worked with the program.

Obtaining teachers' input is essential to the development of any software program that will be used within school settings. We organized a series of panels for teachers to view a prototype version of Maya Math and hear a presentation on the educational objectives of the program. The suggestions that teachers made were extremely useful in helping us to refine the product and place its educational goals in a context that would speak clearly to teacher needs. Teachers' comments on the importance of understanding place value by working with other number systems supported our decision to make the calculator function in any base between two and twenty.

Four classroom teachers were involved in an extensive field test, in which the final version of the software was evaluated in conjunction with the print materials. We were fortunate to have the time available to assess how these materials worked on an ongoing basis within several different classrooms. As a result, many important modifications were made. For example, it became apparent that the best route into understanding the Maya number system was through a comparison with our own base ten number system. Several of the teachers with whom we worked approached the materials with this in mind. They created charts that illustrated the similarities and differences between the two number systems and they designed lessons in which their students were asked to make important comparisons. Many of their final suggestions were incorporated into the print materials.

As mentioned above, without undertaking a formal study it is difficult to know whether what students learn can be attributed to the software materials. In any evaluative study there are always numerous variables to untangle; teaching style, the amount of time students spend using the software, the specific approach students and teachers take, as well as the students' previous knowledge bases can all affect learning outcomes. The formative researcher, however, can use information gathered in the evaluation of comprehensibility to form an impression about what students are learning.

The three groups of users that our research identified helped us to evaluate whether students' understanding of the materials improved over time. Not surprisingly, students in the middle group seemed to develop a better understanding of place value than did students in the other two groups. It is conceivable that students in this group had enough of a knowledge base to build upon successfully. Students in the first group appeared to be hindered by the fact that their understanding of place value was principally algorithmic. As a result, they lacked the conceptual flexibility that is necessary to be a successful user of Maya Math. In contrast, students in the third group, who did have a well-developed conceptual understanding of place value, may have reached a plateau in their capacity to learn more about this particular concept.

In conclusion, I would like to call attention to the fact that this discussion of formative research makes it appear to be a more logical and procedural process than in fact it is. In actuality, formative research is highly *intuitive* and is often learned in the course of carrying out the work. The researcher must possess certain qualities that take time and practice to develop. The ability to engage with students and listen to their concerns, while at the same interpreting with a critical eye, is central to the process. In addition, the capacity to work with diverse groups of people, such as designers, educators, psychologists, and administrators, and juggle what are often conflicting demands is essential. In the final analysis, however, the formative researcher represents the audience who will use the materials. In this case, we served as the students' advocate, ensuring that the process of learning could be challenging, successful, and fun.

Author's Note

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